Dynamical Spontaneous Symmetry Breaking in Quantum Chromodynamics

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The longstanding problems of quantum chromodynamics (QCD) as an $SU(3)_C$ gauge theory, the confinement mechanism and Θ vacuum, can be resolved by dynamical spontaneous symmetry breaking (DSSB), which is essential in generating masses of gauge bosons and hadrons. The confinement mechanism is the result of massive gluons and the Yukawa potential provides hadron formation. The evidences for the breaking of discrete symmetries (C, P, T, CP) during DSSB appear explicitly: baryons and mesons without their parity partners, the conservation of vector current and the partial conservation of the axial vector current, the baryon asymmetry $\delta_B \simeq 10^{-10}$, and the neutron electric dipole moment $\Theta \leq 10^{-9}$.

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Quantum chromodynamics (QCD) [1] with quarks and gluons as fundamental constituents is recognized as the fundamental dynamical theory for strong interactions. One of the longstanding problems is however how to manage QCD in the low energy region. The difficulty in treating QCD at low energy or long range comes from the fact that the coupling constant becomes so strong that conventional perturbation theory fails and confinement takes place in this limit so that the free quark and gluon particles are not observed. Another longstanding problem of QCD is the Θ vacuum [2], which is a superposition of the various false vacua, violating CP symmetry. This paper attempts to solve the problems nonperturbatively in terms of dynamical spontaneous symmetry breaking (DSSB) from QCD, to demonstrate that QND as an $SU(2)_N \times U(1)_Z$ gauge theory for nuclear interactions originates from QCD as an $SU(3)_C$ gauge theory, and to propose that QND for nuclear interactions is the analogous dynamics of the Glashow-Weinberg-Salam (GWS) model as an $SU(2)_L \times U(1)_Y$ gauge theory [3]. The DSSB mechanism is here adopted to strong interactions characterized by gauge invariance, physical vacuum problem, and discrete symmetry breaking. The DSSB mechanism is different from the Higgs mechanism in the GWS model, which has the problem in generating the fermion mass. In this scheme, the only free parameter is the strong coupling constant and several evidences for the violation of discrete symmetries during DSSB are explicitly shown: baryons and mesons without their parity partners, the conservation of vector current and the partial conservation of the axial vector current, the baryon asymmetry $\delta_B \simeq 10^{-10}$ [4], and the neutron electric dipole moment $\Theta \leq 10^{-9}$ [5]. Furthermore, the mechanism of fermion mass generation and the quantization of intrinsic quantum number are proposed as consequences of DSSB due to the Θ vacuum.

The gauge invariant Lagrangian density for QCD with the Θ vacuum [1,2,6] is given by

$$\mathcal{L}_{QCD} = -\frac{1}{2} Tr G_{\mu\nu} G^{\mu\nu} + \sum_{i=1} \bar{\psi}_i i \gamma^\mu D_\mu \psi_i + \Theta \frac{g_s^2}{16\pi^2} Tr G^{\mu\nu} \tilde{G}_{\mu\nu}, \tag{1}$$

where the subscript i stands for the classes of pointlike spinors, ψ for the spinor, and $D_\mu = \partial_\mu - i g_s A_\mu$ for the covariant derivative with the strong coupling constant g_s. Particles carry the local charges and the gauge fields are denoted by $A_\mu = \sum_{a=0} A_\mu^a \lambda^a/2$ with matrices λ^a, $a = 0, .., 8$. The field strength tensor is given by $G_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu - i g_s [A_\mu, A_\nu]$ and its dual is $\tilde{G}_{\mu\nu}$. In the Lagrangian density, the explicit quark mass term is not contained but the bare Θ vacuum term is added as a nonperturbative term to the perturbative term. Since the $G\tilde{G}$ term is a total derivative, it does not affect the perturbative aspects of the theory. The Θ term apparently odd under P, T, and CP operation. An axial current anomaly [7] is taken into account and is linked to the Θ vacuum in QCD [2,6].

The $SU(3)_C$ symmetry for strong force is dynamically spontaneously broken to the $SU(2)_N \times U(1)_Z$ symmetry and then to the $U(1)_f$ symmetry [6,8]. The combination of the confinement mechanism and Θ vacuum explains the DSSB mechanism in QCD analogous to the Higgs mechanism in electroweak theory [3,9]. The Lagrangian density with the Θ vacuum term possesses all the known interaction symmetries perturbatively but it does not conserve discrete symmetries (P, C, T, and CP) . The physical vacuum is not completely symmetric and DSSB from the normal to physical vacuum takes place. This scheme uses dynamical symmetric breaking triggering the axial current anomaly [7] without introducing elementary scalar fields. It aims to have DSSB with gauge interactions alone such as the motivation of technicolor models [10]. The concept of DSSB plays an important role in mass generation in gauge theory which does not have essentially free parameter. DSSB consists of two simultaneous mechanisms; the first mechanism is the explicit symmetry breaking of gauge symmetry, which is represented by the color factor c_f and the strong coupling constant

g_s, and the second mechanism is the spontaneous symmetry breaking of gauge fields, which is represented by the condensation of color singlet gauge fields. Gauge fields are generally decomposed by charge nonsinglet-singlet on the one hand and by even-odd discrete symmetries on the other hand: they have dual properties in charge and discrete symmetries.

Four singlet gauge boson interactions in (1), apart from nonsinglet gauge bosons, are parameterized by the $SU(3)$ symmetric scalar potential:

$$V_e(\phi) = V_0 + \mu^2\phi^2 + \lambda\phi^4 \tag{2}$$

which is the typical potential with $\mu^2 < 0$ and $\lambda > 0$ for spontaneous symmetry breaking. The first term of the right hand side corresponds to the vacuum energy density representing the zero-point energy by even parity singlets. The odd-parity vacuum field ϕ is shifted by an invariant quantity $\langle\phi\rangle$, which satisfies $\langle\phi\rangle^2 = \phi_0^2 + \phi_1^2 + \cdots + \phi_N^2$ with the condensation of odd-parity singlet gauge bosons: $\langle\phi\rangle = (\frac{-\mu^2}{2\lambda})^{1/2}$. DSSB is relevant for the surface term $\Theta\frac{g_s^2}{16\pi^2}TrG^{\mu\nu}\tilde{G}_{\mu\nu}$, which explicitly breaks down the $SU(3)_C$ gauge symmetry for QCD through the condensation of odd-parity singlet gauge bosons. The Θ can be assigned by an dynamic parameter by $\Theta = 10^{-61}\ \rho_G/\rho_m$ with the matter energy density ρ_m and the vacuum energy density $\rho_G = V_e = M_G^4$.

The interaction amplitude in the presence of the gauge boson mass is given by

$$\mathcal{M} = -\frac{c_f g_s^2}{4}\frac{1}{k^2 - M_G^2}J^\mu J_\mu^\dagger \tag{3}$$

where the gauge boson mass M_G is inserted in the gauge boson propagator. Parity or charge conjugation violations due to the condensation of the singlet gauge boson must be taken into account for current densities $J^\mu = [\bar{u}\gamma^\mu u](c_3^\dagger\lambda^a c_1)$ and $J_\mu^\dagger = [\bar{v}\gamma_\mu v](c_2^\dagger\lambda_a c_4)$ where c_i with $i = 1 \sim 4$ represent local color charges. The color vector current is conserved (CVC) but the color axial vector current is partially conserved (PCAC) for strong interactions just as the (V - A) current is conserved but the (V + A) current is not conserved for weak interactions. The effective coupling constant at the strong scale is expressed in analogy with the phenomenological, electroweak coupling constant $G_F = \frac{\sqrt{2}g_w^2}{8M_G^2}$ with the weak coupling constant g_w:

$$\frac{G_R}{\sqrt{2}} = -\frac{c_f g_s^2}{8(k^2 - M_G^2)} \simeq \frac{c_f g_s^2}{8M_G^2} \tag{4}$$

where k denotes the four momentum. Similarly and c_f denotes the color factor c_f. The gauge boson mass is generally reduced by the singlet gauge boson condensation $\langle\phi\rangle$:

$$M_G^2 = M_H^2 - c_f g_s^2\langle\phi\rangle^2 = c_f g_s^2[A_0^2 - \langle\phi\rangle^2] \tag{5}$$

where $M_H = \sqrt{c_f}g_s A_0$ is the gauge boson mass at the grand unification scale, A_0 is the singlet gauge boson, and $\langle\phi\rangle$ represents the condensation of the axial singlet gauge boson. The charge factor c_f used in (5) becomes the symmetric factor with even parity for singlet gauge boson and is the asymmetric factor with odd parity for axial singlet gauge boson. The vacuum energy due to the zero-point energy, represented by the gauge boson mass, is thus reduced by the decrease of the charge factor and the increase of the axial singlet gauge boson condensation as temperature decreases. The essential point is that both the charge coupling constant $c_f\alpha_s$ and the vacuum expectation value $\langle\phi\rangle$ make the initially massive gauge boson lighter. The confinement for the charge electric field can be illustrated more rigorously by considering the Yukawa potential [11] due to massive gauge boson. The Yukawa potential associated with the massive gauge boson is given by $V(r) = \sqrt{\frac{c_f g_s^2}{4\pi}}\frac{e^{-M_G(r-l_{QCD})}}{r}$ which shows the short range interaction for low energy gauge bosons. Gauge boson masses are respectively given by $M_{EW} \simeq 10^2$ GeV at the weak scale and $M_{QCD} \simeq 10^{-1}$ GeV at the strong scale. Effective coupling constants are respectively given by $G_F \simeq 10^{-5}$ GeV^{-2} at the weak scale and $G_R \simeq 10^5$ GeV^{-2} at the strong scale. The effective coupling constant for strong interactions G_R and Fermi weak coupling constant for weak interactions G_F has the ratio $G_R/G_F = (\Lambda_{EW}/\Lambda_{QCD})^2 \approx 10^6$. The gauge boson number density is given by $n_G = M_G^3$: $n_{EW} \approx 10^6$ GeV$^3 \approx 10^{47}$ cm^{-3} at the weak scale and $n_{QCD} \approx 10^{-2}$ GeV$^3 \approx 10^{39}$ cm^{-3} at the strong scale.

DSSB stages are given by $SU(3)_C \rightarrow SU(2)_N \times U(1)_Z \rightarrow U(1)_f$ symmetry for strong force. The electric charge quantizations are $\hat{Q}_e = \hat{I}_3 + \hat{Y}/2$ for the weak force and $\hat{Q}_f = \hat{C}_3 + \hat{Z}_c/2$ for the strong force. The mixing angle for strong interactions $\sin^2\theta_R$ is the indication to the DSSB of the $SU(2)_N \times U(1)_Z$ to the $U(1)_f$ gauge symmetry just as the Weinberg angle for weak interactions $\sin^2\theta_W$ is the indication to the DSSB of the $SU(2)_L \times U(1)_Y$ to the $U(1)_f$ gauge symmetry. These mixing angles relate the strong coupling constant to the coupling for massless gauge boson dynamics, $\alpha_f = \alpha_n\sin^2\theta_R = \alpha_n/4$ with the nuclear coupling constant α_n, and the weak coupling constant to the coupling for photon dynamics, $\alpha_e = \alpha_w\sin^2\theta_W = \alpha_w/4$ with the weak coupling constant α_w, respectively. The charge mixing angle is closely related to massive gauge boson and massless gauge boson generation. In the phase transition process of the $SU(3)_C \rightarrow SU(2)_N \times U(1)_Z \rightarrow U(1)_f$ symmetry, there are massive bosons $A_\mu^\pm = \frac{1}{\sqrt{2}}(A_\mu^1 \mp iA_\mu^2)$ and $B_\mu^0 = \cos\theta_R A_\mu^3 - \sin\theta_R A_\mu^8$. The fourth vector orthogonal to B_μ is identified as massless gauge boson: $C_\mu = \sin\theta_R A_\mu^3 + \cos\theta_R A_\mu^8$ with the mass $M_C = 0$. Two gauge fields B_μ and C_μ are orthogonal combinations of the gauge fields A_μ^3 and A_μ^8 with the mixing angle θ_R. The generators of this scheme satisfy the relation [12]

$$\hat{Q}_f = \hat{C}_3 + \hat{Z}_c/2 \tag{6}$$

with the longitudinal component of the colorspin operator $\hat{C}_3$ and the hyper-color charge operator $\hat{Z}_c$ so that the corresponding current density is presented by $j^f_\mu = J^3_\mu + j^8_\mu/2$. The interaction in the mixing charge current can provide the relation $g_f = g_n \sin\theta_R = g_z \cos\theta_R = g_b \cos\theta_R \sin\theta_R$ is used.

During phase transition, the discrete symmetries of time reversal (T), parity (P), and charge conjugation (C) are violated so as to make matter particles massive: since the product symmetry CPT remains intact, CP symmetry is violated. These violations are analogous to the nonconservation of the (V + A) current in weak interactions and the axial vector current in strong interactions. The breaking of discrete symmetries through the condensation of singlet gauge bosons causes the baryon-antibaryon asymmetry with $\Theta_{QCD} \simeq 10^{-12}$ at the strong scale. Discrete symmetries are in general not broken perturbatively but is broken nonperturbatively. The breaking of discrete symmetries is supported by looking at the observation of pseudoscalar and vector mesons while their parity partners, scalar and pseudovector mesons, are not observable at the strong scale; similarly, there is no baryon octet and decuplet parity pairs. This resolves the $U(1)_A$ problem; the absence of the $U(1)_A$ particle is due to the nonconservation of the color axial vector current. Singlet gauge bosons condense in the formation of the hadron and the condensation is relevant for the partial conservation of axial vector current (PCAC)

$$\partial_\mu J^5_\mu = \frac{N_f c_f g_s^2}{16\pi^2} Tr G^{\mu\nu} \tilde{G}_{\mu\nu} \tag{7}$$

with the flavor number N_f and the conservation of vector current (CVC) $\partial_\mu J_\mu = 0$: this is an example of parity violation. C violation in baryon as three quark combination is shown in the number difference of the proton and antiproton as observed in the baryon asymmetry of the present universe; the baryon asymmetry $\delta_B \approx 10^{-10}$ requires C, T, and CP violations. Based on observation, there is the tiny CP violation in the nonvanishing electric dipole moment for the neutron $d_n = 2.7 \sim 5.2 \times 10^{-16} \Theta\ e$ cm [5], which is reflected by the Θ vacuum problem $\Theta_{QCD} \leq 10^{-9}$.

Massless gauge bosons (photons) as Nambu-Goldstone (NG) bosons [13] are created during the DSSB. Massless gauge bosons are the quanta of the radiation field that describes classical light. Phase transition from $SU(2)_L \times U(1)_Y$ to $U(1)_e$ gauge symmetry and phase transition from $SU(2)_N \times U(1)_Z$ to $U(1)_f$ gauge symmetry produce massless photons with two transverse polarizations. They are massless excited modes associated with the generators of the $U(1)_e$ gauge symmetry for weak force and with the generators of the $U(1)_f$ gauge symmetry for strong force. The explicit examples of massless gauge bosons for strong force are the intrinsic vibration modes in nuclear excitation with the typical energies $0.1 \sim 10$ MeV as noticed by the gamma decays. Massless gauge mode (photon) for the $U(1)_f$ gauge theory originated from color charges has the coupling constant $\alpha_f = \alpha_s/16 = \alpha_n \sin^2\theta_R \simeq 1/34$, which is distinct from the coupling constant $\alpha_e = \alpha_w \sin^2\theta_W \simeq 1/137$ mediated by the photon for the $U(1)_e$ gauge theory. However, the massless photon produced by the combination of color and isospin charges has the coupling constant $\alpha_e \simeq 1/137$ at strong scale; the conservation of the proton number is the analogy of the conservation of the electron number. The analogy carriers over to a correspondence between the theory of electromagnetic radiation in thermal equilibrium and the theory of color radiation in thermal equilibrium. Each harmonic oscillator of frequency ω can only have the energies $(n + 1/2)\omega$, where $n = 0, 1, 2 \cdot\cdot$. This fact leads to the concept of massless gauge bosons as quanta of the color field whose state is specified by the number n for each of the oscillators known as massive gauge bosons. Massless gauge bosons mediate the Coulomb potential ($\sim 1/r$) and the condensation of singlet gauge bosons makes the confinement potential. The average photon occupation number in the thermal equilibrium is given by $f_p = 1/(e^{E/T} - 1)$. Massless photons are quantized by the maximum wavevector mode $N_\gamma \approx 10^{29}$ and the total photon number $N_{t\gamma} = 4\pi N_\gamma^3/3 \approx 10^{88}$. The number density of massless gauge bosons is given by $n_\gamma = 2\zeta(3)T^3/\pi^3$: $n^{QCD}_{t\gamma} \approx 10^{36}$ cm^{-3} at the strong scale.

The fine structure constant α_s for strong interactions is measured by several experiments [14]: $\alpha_s(M_Z) \simeq 0.12$ at the momentum of the Z boson mass $q = M_Z$ and $\alpha_s(q) \simeq 0.48$ at the momentum of nuclear energy $q \simeq 300$ MeV. Strong coupling constants for baryons are $\alpha_b = c^b_f \alpha_s = \alpha_s/3$, $\alpha_n = c^n_f \alpha_s = \alpha_s/4$, $\alpha_z = c^z_f \alpha_s = \alpha_s/12$, and $\alpha_f = c^f_f \alpha_s = \alpha_s/16$ as symmetric color interactions and $-2\alpha_s/3$, $-\alpha_s/2$, $-\alpha_s/6$, and $-\alpha_s/8$ as asymmetric color interactions: $c^n_f = \sin^2\theta_R$ and $c^f_f = \sin^4\theta_R$. The color factors introduced are $c^s_f = (c^b_f, c^n_f, c^z_f, c^f_f) = (1/3, 1/4, 1/12, 1/16)$ for symmetric interactions and $c^a_f = (-2/3, -1/2, -1/6, -1/8)$ for asymmetric interactions. The symmetric charge factors reflect intrinsic even parity with repulsive force while the asymmetric charge factors reflect intrinsic odd parity with attractive force. Asymmetric configuration for attractive force is confined inside particle while symmetric configuration for repulsive force is appeared on scattering or decay processes. The color factors described above are pure color factors due to color charges but the effective color factors used in nuclear dynamics must be multiplied by the isospin factor $i^w_f = \sin^2\theta_W = 1/4$ since the proton and neutron are an isospin doublet as well as a color doublet. Nucleons as spinors possess up and down colorspins as a doublet just like up and down strong isospins:

$$\begin{pmatrix} \uparrow \\ \downarrow \end{pmatrix}_c, \ \uparrow = \begin{pmatrix} 1 \\ 0 \end{pmatrix}_c, \ \downarrow = \begin{pmatrix} 0 \\ 1 \end{pmatrix}_c. \tag{8}$$

This implies that conventional, global $SU(2)$ strong isospin symmetry introduced by Heisenberg [15] is postulated as the combination of local $SU(2)$ colorspin and local $SU(2)$ weak isospin symmetries [8]. Therefore, the effective color factors are given by

$$c_f^{eff} = i_f^w c_f = i_f^w (c_f^b, c_f^n, c_f^z, c_f^f) = (1/12, 1/16, 1/48, 1/64) \tag{9}$$

for symmetric configurations. For example, the electromagnetic color factor for the $U(1)_f$ gauge theory becomes $\alpha_f^{eff} = \alpha_s/64 \simeq 1/137$ when $\alpha_s \simeq 0.48$ at the strong scale [14].

Matter mass generation has features represented by the Θ vacuum, dual Meissner effect, and constituent particle mass [6]. The matter mass is attributed from the dual pairing process due to dielectric mechanism, which violates the gauge symmetry and discrete symmetries. The relation between the gauge boson mass and the fermion mass is given by

$$M_G = \sqrt{\pi} m_f c_f \alpha_s \sqrt{N_{sd}} \tag{10}$$

where N_{sd} is the difference number of even-odd parity singlet fermions in intrinsic two-space dimensions. The above relation stems from the dual pairing mechanism $M_G = g_{sm}^2 |\psi(0)|^2 / m_f$, in analogy with electric superconductivity, where $|\psi(0)|^2 = (m_f c_f \alpha_s)^3$ is the particle probability density and $g_{sm} = 2\pi n/\sqrt{c_f} g_s = 2\pi\sqrt{N_{sd}}/\sqrt{c_f} g_s$ is the color magnetic coupling constant according to the Dirac quantization condition [16]. The particle number N_{sd} is the difference number between the number N_{ss} of singlet particles interacting with charge symmetric configurations and the number N_{sc} of condensed particles interacting with charge asymmetric configurations: $N_{sd} = N_{ss} - N_{sc}$. The fermion mass formed as the result of confinement mechanism is composed of constituent particles: $m_f = \sum_i^N m_i$ where m_i is the constituent particle mass. In the above, N depends on the intrinsic quantum number of constituent particles: $N = N_{sd}^{3/2}$. For examples, $N = 1/B$ with the baryon number B for the constituent quark in the formation of a baryon and $N = 1/M$ with the meson number M for the constituent quark in the formation of a meson. A fermion mass term in the Dirac Lagrangian has the form $m_f \bar{\psi}\psi = m_f(\bar{\psi}_A \psi_V + \bar{\psi}_V \psi_A)$ where the mass term is equivalent to a helicity flip. Vector fermions are put into $SU(2)$ doublets and axial-vector ones into $SU(2)$ singlets. In the dual pairing mechanism, discrete symmetries P, C, T, and CP are dynamically broken due to massive gauge bosons [6]. Electric monopole, magnetic dipole, and electric quadrupole remain in the matter space but magnetic monopole, electric dipole, and magnetic quadrupole condense in the vacuum space as the consequence of P violation. Antibaryon particles condense in the vacuum space while baryon particles remain in the matter space as the result of C and CP violation at the strong scale: the baryon asymmetry $\delta_B \simeq 10^{-10}$ [4]. The electric dipole moment of the neutron and no parity partners in hadron spectra are the typical examples for P, T, and CP violation at the strong scale. The fine or hyperfine structures of a fermion mass include spin-spin, isospin-isospin, and colorspin-colorspin interactions due to intrinsic angular momenta of $SU(2)$ gauge theories:

$$\triangle E \propto \alpha_m \frac{\vec{s}_i \cdot \vec{s}_j}{m_i m_j} |\psi(0)|^2 + \alpha_i \frac{\vec{i}_i \cdot \vec{i}_j}{m_i m_j} |\psi(0)|^2 + \alpha_s \frac{\vec{\zeta}_i \cdot \vec{\zeta}_j}{m_i m_j} |\psi(0)|^2 \tag{11}$$

where α_m, α_i, and α_s are respectively coupling constants. The approach can be applied to investigate the masses of hadrons, which justify the constituent quark model as an effective model of QCD at low energies from this viewpoint. If interactions due to colorspin and isospin contributions are absorbed to the constituent quark mass, the meson mass of the conventional constituent quark model is obtained:

$$m_m = m_1 + m_2 + A \frac{\vec{\sigma}_1 \cdot \vec{\sigma}_2}{m_1 m_2} \tag{12}$$

where $\vec{\sigma}_1 \cdot \vec{\sigma}_2 = 4\vec{s}_1 \cdot \vec{s}_2 = 1$ for vector mesons and $\vec{\sigma}_1 \cdot \vec{\sigma}_2 = -3$ for pseudoscalar mesons are given and $A = \frac{8\pi g_s^2 |\psi(0)|^2}{9}$. By the same token, the baryon mass of the conventional constituent quark model is obtained:

$$m_b = m_1 + m_2 + m_3 + A' \sum_{i>j} \frac{\vec{\sigma}_i \cdot \vec{\sigma}_j}{m_i m_j} \tag{13}$$

where $A' = \frac{4\pi g_s^2 |\psi(0)|^2}{9}$. Since $\sum \sigma_i \cdot \sigma_j = 4 s_i \cdot s_j = 2[s(s+1) - 3s(s+1)]$ with the total spin $\vec{S} = \vec{s}_1 + \vec{s}_2 + \vec{s}_3$, $\sum \vec{\sigma}_i \cdot \vec{\sigma}_j = 3$ for decuplet baryons and $\sum \vec{\sigma}_i \cdot \vec{\sigma}_j = -3$ for octet baryons are given. The constituent quark model illustrates reasonable agreement in hadron spectra within a few percent deviation.

This study proposes that the longstanding problems of quantum chromodynamics (QCD) as an $SU(3)_C$ gauge theory, the confinement mechanism and Θ vacuum, can be resolved by dynamical spontaneous symmetry breaking (DSSB) through the condensation of singlet gluons and quantum nucleardynamics (QND) as an $SU(2)_N \times U(1)_Z$ gauge theory is produced. DSSB in QCD is essential in generating masses of gauge bosons and hadrons. During DSSB, common features in gauge theories appear: massive gauge boson, massless gauge boson (photon) as the NG boson, nonperturbative spontaneous breaking of discrete symmetries, charge mixing angle, and coupling constant hierarchy. G_R is realized as the effective coupling constant for a massive gluon, $G_R/\sqrt{2} =$

$c_f g_s^2/8M_G^2 \approx 10$ GeV^{-2} with the gauge boson mass $M_G = M_{QCD} \approx 10^{-1}$ GeV, the strong coupling constant g_s, and the color factor c_f. The condensation of the singlet gauge field $\langle\phi\rangle$ triggers the current anomaly and subtracts the gauge boson mass, $M_G^2 = M_H^2 - c_f g_s^2 \langle\phi\rangle^2 = c_f g_s^2 [A_0^2 - \langle\phi\rangle^2]$, as the vacuum energy. Spontaneous symmetry breaking in gauge theories is in this work extended to dynamical spontaneous symmetry breaking mechanism, which has only one free coupling constant, to generate gauge boson masses and fermion masses as well as to explain nonperturbative discrete symmetry breaking in strong interactions.

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